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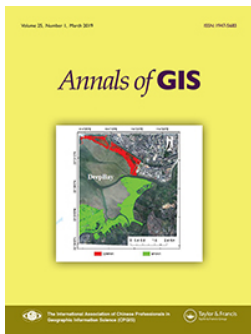
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Visualizing urban sprawl effects of a Tunisian city: a new urban spatial configuration of Monastir

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ABSTRACT

The purpose of this research is to study the dynamics associated with the physical transformations of the Tunisian city of Monastir between 1956 and 2013. Beyond the description and classification of urban forms of three different phases of Monastir's development, this research evaluates how urban changes underwent a rapid growth. The objective is to identify how the transformations undergone, from its original Medina transformation project to the contemporary city, can be apprehended using the underlying urban configuration and its evolution. The main question to address is as follows: how configurational urban changes over time have an impact on the way humans are connected throughout the organization of the city? As a theoretical background and methodology, our research is based on the theory of Social Logic of Space, and that considers the city as a dynamic system, and acknowledges circulation as the driving force behind urban morphological change. The series of investigations developed by our case study reveal the urban planning influence on the urban sprawl of the city of Monastir. It also shows the importance of centralities and accessibility of the urban forms and their effect on the distribution of land uses, and the role of the central/periphery dualism.

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Space syntax; axial map;
centre-periphery; land use;
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1. Introduction

The search for a better understanding of the relationships between the city centre and peripheries has become an important research issue in recent years (Gordon and Wong 1985; Haines 1986; Rosenthal 2000; Tacoli 2003). The intrinsic urban morphology of the different areas of a given city is one of the factors that intervene to configure various periphery types and centre-periphery relationships. City's peripheries can be even isolated structures, and considered as invisible territories avoided by both their own dwellers and city centre inhabitants; this is particularly reflected by many American and African cities which are often fragmented and made of isolated peripheries, or difficult to access (Reid 1997; Kohlsdorf 2002; Adebayo 2012). However, there are a few cases where peripheries can be well connected with the city centre, thus improving their potential in order to build a rich, plural and attractive urban landscape that integrates its social fabric as this happened in the Ghanaian city of Accra (Doan and Odoro 2012). In this context, today's peripheral areas are no longer only the result of the organization of people's daily lives, but also urban areas in their own rights, redefining, questioning and recomposing the city centre's centrality (François, Dubois-Taine, and Challas 1997).

1.1. Cities urban networks

The urban network is an imprint of the city's history, containing traces of different urban growth, planning and social processes. Each configuration generates some specific properties and relationships that should be studied for a better understanding of the underlying processes that shaped the city. Urban morphology, as a specific field of knowledge on the urban structure and transformations, has an unquestionable legitimacy to contribute to more informed interventions in the city (Pinho and Oliveira 2009). Morphological analysis makes it possible to summarize the changes and trends of urban spatial structure and urban form (Jianquan 2011; Mohajeri, French, and Batty 2013). Over the past two decades, space syntax has provided computational support for the development of spatial morphological studies, in particular for the analysis of urban systems (Jiang, Claramunt, and Klarqvist 2000). A series of analytical tools and measures have been applied by space syntax studies to characterize the structural properties of the city in syntactic or morphological terms, this even leading to structurally categorize cities (Holanda 2002). As suggested by Hillier (2009), centralities that appear are likely to be the result of global and local

factors. Global factors reflect potential relations and movements between emerging centres with respect to the system as a whole, while local factors exhibit internal properties and movements inside these centres. We argue that the social and structural properties of a given city can be dependably determined and described to a certain degree. Our aim is to explore how space syntax can reveal the main evolution patterns of the city of Monastir, and by taking into account complementary urban planning and socio-economic factors. A few previous studies have studied the evolution of cities in Tunisia (Meddeb 2014). The specific case and the impact of the management of the Medina of Monastir have been also studied (Harzallah 1980). In a previous work, the accessibility of the old city of Monastir has been studied (Bouzarrou et al. 2016). However, there is still a lack of research that studies the urban sprawls of the city of Monastir, the role of directed planning in this process, as well as the correlation between accessibility and functional patterns.

The emergence of novel peripheral areas and centres is a trend particularly reflected by the city of Monastir. In fact, several questions still remain: is the current polycentrism further observed in this paper the result of an urban planning process? Does the historical centre still maintain its attractivity and function? What kind of structural model emerges from such evolution? We applied several space syntax integration measures at the local and global levels in order to confirm the polycentric structure of the city of Monastir and the emergence of different central areas.

1.2. The case of Monastir, a Sahelian city

It has been observed that the growth of urban population is one of the most important driving forces of change in urban systems where cities expand horizontally and vertically to accommodate new comers (Hashem and Balakrishnan 2015). Indeed, population growth has a significant impact on the evolution of the road network and land uses. In particular, when considering the governorate of Monastir, the population was 515,300 inhabitants in 2010, and population density 505 hab/km² (and reaches even 707 hab/km² for the coastal area), compared with 67 hab/km² on average for Tunisia. The natural population growth rate is 2% in 2010, being higher than the national rate of 1.05%. This trend is partly due to the migration of the interior regions to the littoral (Mangos and Claudot 2013). Along these figures and a diachronic approach, our objective is to investigate the effect of the rapid and continuous expansion of the governorate of Monastir on the accessibility and the urban

configuration of the contemporary city as evaluated by space syntax experiments.

Monastir has been the object of a spectacular urban sprawl. In order to study the process of morphological transformation, all the factors involved in the transformation of the urban space should be taken into account, including the network and built environments. This first implies to study and evaluate the physical transformations of an urban area, and second to relate these changes to the economic and political factors that eventually guide and generate these processes (Bouzarrou et al. 2016).

This paper has the first objective of deriving a spatial representation and interpretation of the growth process of urban sprawl of the city of Monastir in the last 50 years. In a previous work, we have studied the spatial and urban morphology of the old city of Monastir (Bouzarrou et al. 2016). Our aim is also to structurally and quantitatively evaluate the evolution of the urban space thanks to the application of a series of space syntax measures. A second important objective of this research is to derive a spatial representation of the structure of the city with a specific focus on the centrality/periphery dualism, and to study the intimate relationship between the structure of the city and the land use. Next, and by taking the case of Monastir as a representative example of a Sahelian city, our intention is to discuss further implications of our findings.

The old Medina of Monastir as shown in Figure 1 has a built area of 184,877 m² while the new centre has an area of 425,241 m². The photos exhibited in Figures 1 and 2 showed a transition phase in which the urban layout dramatically changed from narrow alleys to wider streets. The cartography of the area corresponding to Monastir's layout is studied through a diachronic approach, considering as reference, three background maps which respectively represent three different urban morphological times: after independence (1956), after the project established by the architect Cacoub (1960) and metamorphism engendered by the urban sprawl (2013) (Figure 3).

The urban development project of Monastir as planned in 1974 by urban politics had a strong impact, passing from an arabo-musulman planning system (e.g. the medina) to a 're-dimensioned' urban street system for the new centre. The project of the architect Cacoub was principally an operation of street widening (Figure 2(a)). Until 1960, Monastir was a 'walking city', traffic was slow moving, and the streets were narrow and crooked. The widening of some Medina's streets was part of the operation. Figure 2 (e) shows the Medina after the management project and the emergence of larger streets. This period was a very highly active one for municipal-driven urban planning.

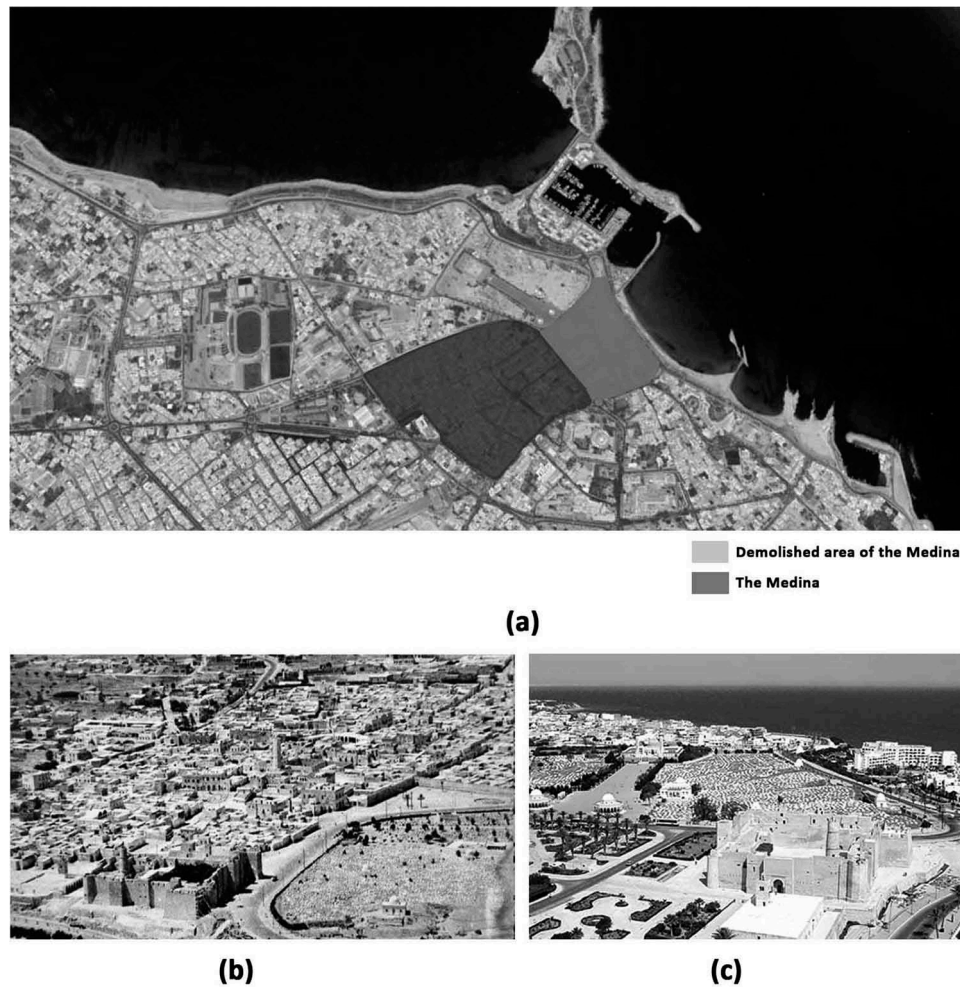


Figure 1. (a) Satellite picture of Monastir with the localization of the demolished area of the Medina; (b) Monastir Medina picture in 1956 before demolition; (c) Monastir picture in 1994 after demolition.

2. Methodological steps

The concept of axial line has been defined as the longest straight line representing the maximum extension of a point of space. Although different computational implementations of the derivation of axial lines can indeed lead to slightly different axial line networks in function of the points in space considered, such approximations can be considered as relatively sound when the algorithms implemented to derive axial lines maximize the search for longest axial lines. Another advantage of the axial line representation is that it integrates a cognitive dimension in the approach, enlarging the usual space syntax approach which is mainly structural (Penn 2003). Within many space syntax studies, axial maps are privileged solutions applied to model the spatial structure of an urban system. The connectivity of an axial line measures the number of lines that directly intersect that given axial line. It also denotes the number of immediate neighbourhoods of an axial line (Jiang and Claramunt 2002).

Connectivity shows how often a street is connected to another street. The integration of an axial line is a value which indicates the degree to which an axial line is more integrated, or segregated from the system as a whole. The measure of integration is derived from the measure of depth. Depth is defined, for a particular axial line, as the summation of the number of steps to reach other axial lines (i.e. a step represents the un-weighted distance between two axial lines that intersect in the axial map). A space is said to be 'deep' if that axial line is relatively far away from other axial lines; equally a space is said to be 'shallow' if it is relatively close from other axial lines. The *Mean Depth* (MD) of a line is given by

$$MD_i = \frac{\sum_{j=1}^n d_{ij}}{n-1} \quad (1)$$

where n is the total number of axial lines and d_{ij} is the depth of the i th axial line from the j th axial line.

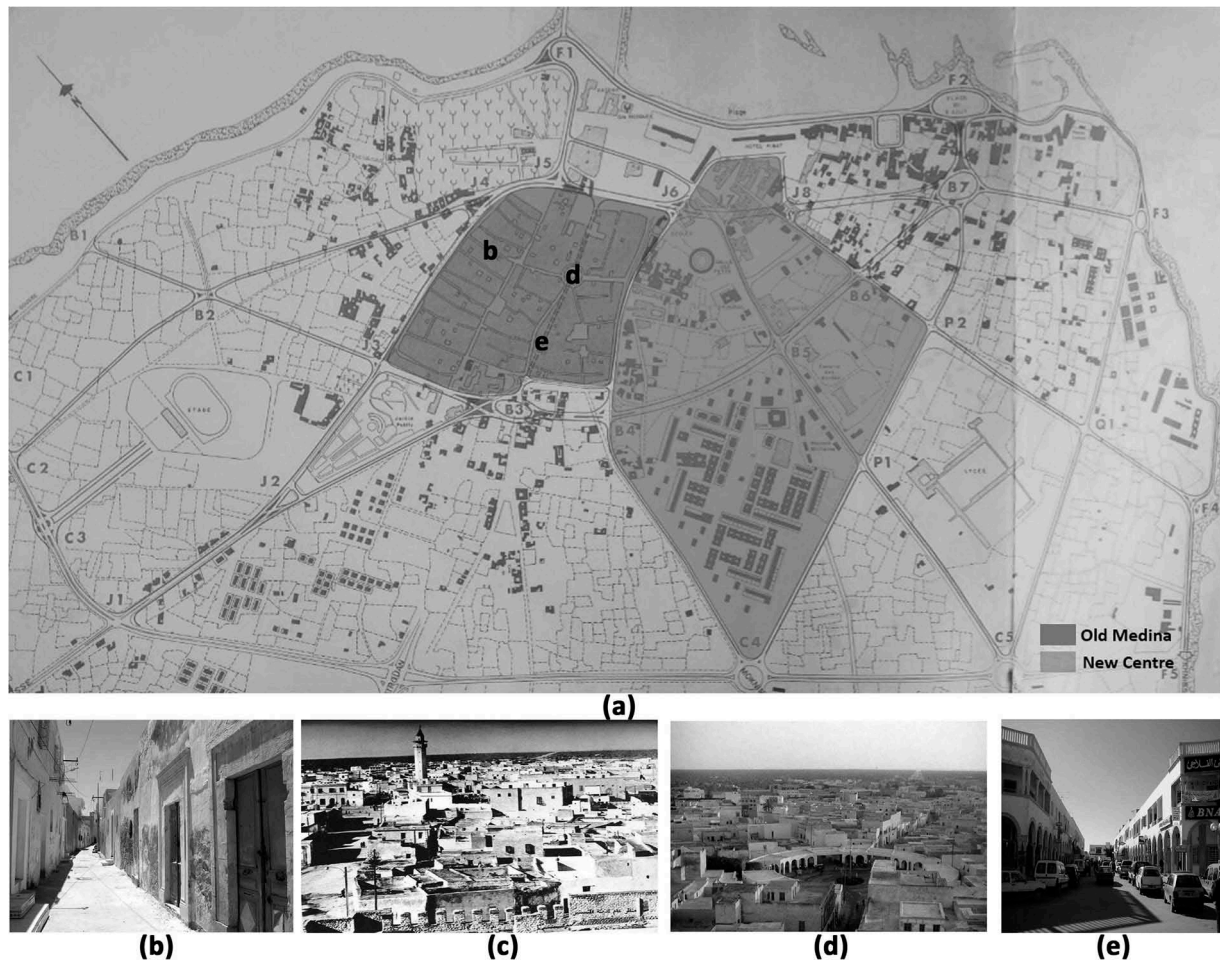


Figure 2. (a) Map of the project of Cacoub with the localization of the historic and the new centre of Monastir in 1974; (b) Monastir Medina picture in 1960; (c) Monastir Medina picture in 1964; (d) Monastir Medina picture in 1974. (e) Monastir Medina picture in 1980.

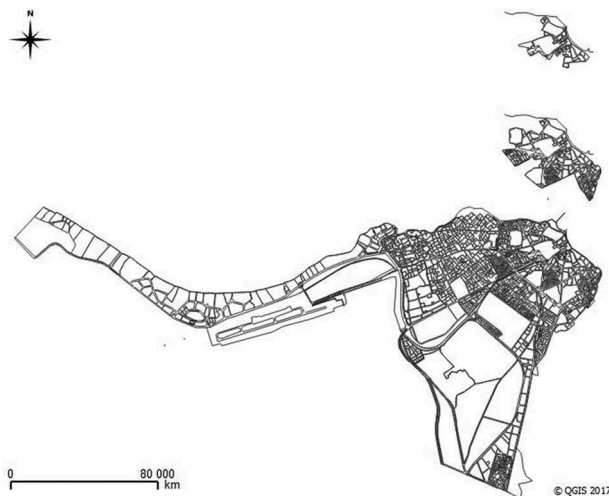


Figure 3. Morphological phases of Monastir urban sprawl (from above to below): (1956), (1974) and (2013).

Next the measure of *Integration* of a given axial line i is derived from the measure of *Relative Asymmetry* (RA_i) which is given as follows:

$$RA_i = \frac{2(MD_i - 1)}{n - 2} \quad (2)$$

The *Local Integration* of a given axial line is defined as its measure of *Integration* at the radius 3 (all lines at three topological steps from the root). This measure gives a local picture of integration. The value of *Integration*, as well the one of *Local Integration* at the local level, reveals how accessible/connected an axial line is in relation to other lines in an urban layout. Accordingly, the street segments of an urban network can be ranked from the most integrated (e.g. red axial lines in Figure 4) to the most segregated one (e.g. blue axial lines in Figure 4) (Klarqvist 1993). By generalizing this measure, the *Integration Core* has been defined as the 10% most integrated streets in a given urban network (Hanson and Hillier 1987). The integration maps exhibited in the following figures show the respective *Integration* values of the axial lines of the Monastir urban layout. Space syntax studies showed that the most integrated axial lines are the frequently used ones, showing



Figure 4. Axial maps for the three temporal phases of the analysis (from above to below): 6a (1956), 6b (1974) and 6c (2013).

a close relationship between the structure and the function of the city (Hillier 1996).

Another key measure of space syntax commonly used to identify some centrality structural patterns is the measure of *Choice*. *Choice*, originally introduced as *Betweenness* by Freeman (1977), is a measure of the importance of a given node in a graph. That literally tells how many times a node happens to be in the shortest paths between all other nodes. It can also be computed for the links connecting the nodes in a similar way. It is computed as follows:

$$C_B(P_i) = \sum_j \sum_k \frac{\sigma_{jk}(P_i)}{\sigma_{jk}} (j \neq k) \quad (3)$$

where $\sigma_{jk}(P_i)$ is the total number of shortest paths from nodes P_j to P_k and σ_{jk} is the number of those paths through P_i (Freeman 1977).

In other words, *Integration* measures reflect how easy it is to go from a street segment to all other street

segments in the network, thus indicating the potential of a street segment regarding to-movement. In contrast, *Choice* measures how expected is it for an axial line to be chosen on paths from one axial line to another one in the network system, indicating its potential for through-movement (Hillier 2005). Therefore, we consider *Integration* and *Choice* as spatial measures that should help to provide a better understanding the social logic that space might reveal, as well as the potential link between these spatial measures and the likelihood for movement and land-use evolution in the layout of the city of Monastir.

Synergy is a measure of the correlation between the *Local Integration* and *Integration*. It reflects how the global structure of an entire entity like a city or city region is reflected in the local structure of space. *Local Integration* is not as local as *Connectivity*, but it is the best correlate, for example, of pedestrian movement rates, and seems to give a good indication of the local pedestrian scale structure of some urban areas. In fact, it is composed of qualities of physical-spatial association of the city which bolster the activities and conduct of individuals, especially out in the public space. Spatial synergy is accomplished through a particular method in organizing buildings, structures, specialized offices and plantings to shape open spaces (space portions or places). It is accomplished through the way these are interrelated (i.e. relation and communication) inside the urban fabric. It is likewise accomplished through the level of availability of all such characterized puts inside a settlement unit ('universal distance') (Agael and Özer 2017).

Hillier (1996) suggested that the degree of intelligibility can be predicted by looking at the form of the scatter. In the lexicon of space syntax, *Intelligibility* is a technical term with a specific and quantitative definition, whereas in by usage, the term refers to the more general, quantitative characteristics which relate to the capability of being understood (Hillier 1996). It has been suggested by Hillier (1996) that r^2 value of greater than 0.45 represents an 'intelligible system'. Considering the importance of emerging residential structure, we should also 'examine the local intelligibility', which mean the correlation between connectivity and local integration (Hillier 1996).

We applied an axial map analysis using the measure of *Integration* that evaluates the *to-movement* potential of a given axial line, while the measure of *Choice* evaluates the *through-movement* potential of a given axial line in the graph. These two measures represent two complementary forms of movement in an urban network by evaluating either the potential shortest movements to all other locations in the graph (i.e. *Integration*) or evaluating the capacity of a given location to lie in a path of all shortest paths between all

locations of the graph (i.e. *Choice*). Moreover, there two syntactical properties are likely to reflect the type of land use that would fit best in this space (Charalambous and Mavridou 2012). Finally, the correlation between *Choice* and *Integration* measurements should be examined, since this represents the likeliness of an area having a centrality quality, which could generate contact (Vaughan, Dhanani, and Griffiths 2013). Furthermore, we plan to discuss the possible correlation between these two syntactical measures in order to evaluate how spatial accessibility can 'attract' land uses.

The results illustrated in Figure 4 are shown in a chromatic scale, and where axial lines of red–yellow colours represent high–low values, respectively (all calculations have been made using DepthmapX© developed at the Bartlett Space Syntax Laboratory at University College London).

3. Diachronic evolution of syntactic structures

One cannot understand the development of Monastir without taking into account the action of modernization of the city. Three maps for the most important successive phases of the city have been generated in order to show how different patterns and measures of *Integration* and *Choice* reflect different structural properties and change from one phase to another.

A visual analysis of the evolution of *Integration* values reveals that the strategic centrality of the urban network dates was already apparent in 1956 (Figures 5–7). Ever since, the city development project has shifted the 'new' integration core towards the South, as observed in the 1974 map and further consolidated in the following period (2013 maps). The 2013 axial map shows the transition from the closed and compact *Integration Core* to a rather linear one, denoting clearly a disintegration and dispersion of urban structures as the result of incautious layout adjustments and incidental locations of extensive commercial centres (Hillier, 2000). The main patterns that appear from these successive phases and from the application of space syntax measures are as follows:

- In the *first phase*, the axial map valued with *Integration* measures shows that the number of well-connected streets is limited and concentrated in the area of the Medina, and denoted by the most connected roads in the old Monastir. The axial line map analysis shows similar results regarding highest *Choice* values. *Choice* values show that the city of Monastir has a *Choice Core* which is a fully connected and a linear hub that started with a slightly overstated beginning from the northern part of Medina up to the eastern part and passing through the centre. The

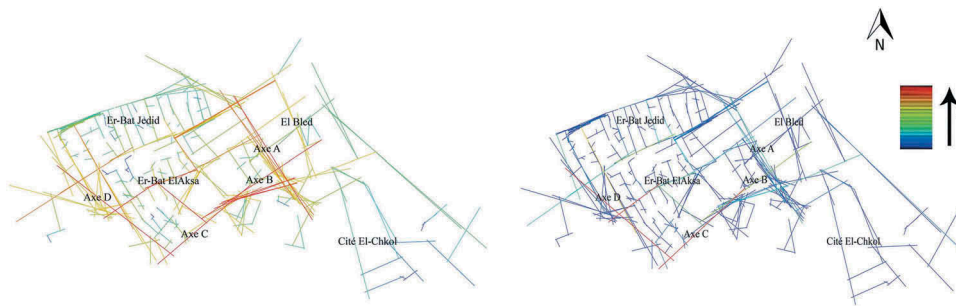


Figure 5. Integration and choice urban maps in 1956.

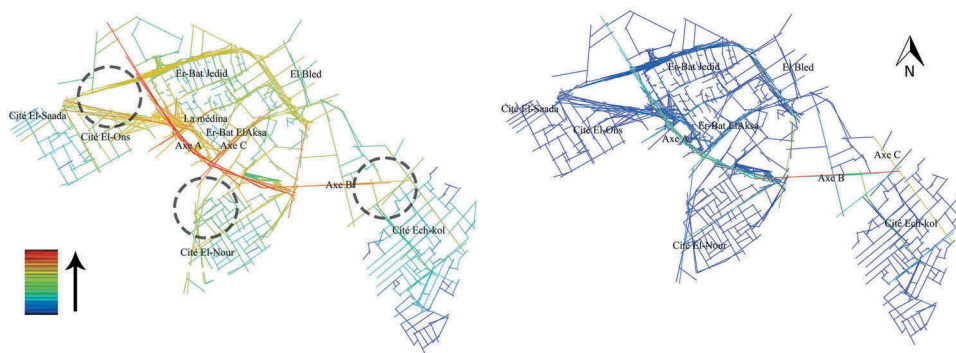


Figure 6. Integration (R_n) and choice (R_n) maps in 1974 *with high n values.



Figure 7. Integration (R_n) and choice (R_n) maps in 2013 *with high n values.

Integration Core is clustered along the Medina 'circle'. This *Integration Core* consists of one series of axial lines within which the longest one is the most integrated, and it is intersected with a group of passing through axial lines while the second rank level of the highest *Integration* represents the interface between the *Integrated Core* and the adjacent spatial system of low integration lines towards the most segregated axial lines of the dead end alleyways along the Monastir's periphery (Figure 5). The segregated areas include the peripheral roads at the boundary of the city wall in East and West sides. As for the *Integration Core*, the *Choice Core* of the axial map is defined by the 10% of all the streets with *Choice* values higher than the rest (Hanson and Hillier 1987). It also appears that streets with high *Integration* and *Choice* values in the area contain commercial and mixed uses, and are characterized by short and twisted street networks (Figure 2). Finally, the local structure of the city fabric in 1956 exhibits an average value of *Synergy* of 0.77, denoting a reasonable correlation among *Local Integration* and *Integration* values. Similarly, the *Intelligibility* values reveal how the old town of Monastir as modelled in 1956 where the average value of the system is 0.57, implying a relative intelligible system that reflects a sensible degree of correlation between *Connectivity* and *Integration* values. In fact, *Intelligibility* can be defined as the integration of each space into the whole system, that is, the degree to which what we can see and experience from the spaces that make up the system and what we cannot see.

- In the second phase, the axial map analysis shows a significant increase in the number of connected

streets, resulting from the fast urban development and expansion caused by rapid population growth. The axial map also reveals that the *Integration Core* has moved slightly to the north-east side, and most connected streets are concentrated in the new centre recently planned city by Cacoub (Figure 2(a)). As revealed by the axial map of the second semester of 1974, the urban system has increased its number of line segments by five times, but whilst average segment line length remains almost the same. The main integrated feature of the urban system is the axial lines connecting the old Medina to the new centre, which is also directly connected with three other red axial lines presenting the highest values of *Integration*, followed by four orange axial lines connecting the new emerging centres in the southern part as reflected in Figure 7. Finally, the lowest level of *Integration* is denoted by several short yellow lines along the western side. Both *Integration* (1.26) and *Local Integration* (2.03) average values have increased. It is worth mentioning here that at that time most of the displacements in the city of Monastir were made by walking (Dino 2016) as shown in Figure 1(e). This shows that the new urban configuration dynamics is likely to favour the movement of people. These measures lead us to formulate the reflection that the emergence of many activities such as equipment and commercial services in the urban system denotes the vitality of the city. Several grid-like patterns of urban planning interventions are reflected in this axial system, a characteristic settlement form of colonization that for Monastir was issued from the project of town modernization established in 1974. A notable trend

is that the connectivity between the old Medina and the new centre is ensured by the main street. The new parts of the urban system are just emerging, hence resulting in a slight increase of the average connectivity value of the system to 4.91. The planning intervention of 1974 slightly decreased the *Synergy* of the system to 0.67, having a functional impact on the historical centre that causes the decline of the importance of the function and attractiveness of the historical centre, and rather favouring the emergence of the new centre. With the increasing concentration of businesses, shops, services and offices (Figure 8), the new centre of the city (denoted in Figure 1(a)) was consolidated as the main core in 1974. In fact, the changes that happened between 1956 and 1974 harmed many of the activities of the historical centre and then generated a novel form of urban functional centrality. Currently, the old centre of Monastir still concentrates the main commerce activities, but a series of important equipment have been created in the new extension of the city. *Intelligibility* is another parameter whose value has

decreased. At this stage, the average *Intelligibility* is 0.35. Therefore, it can be said that the *Intelligibility* value of the study area remained weak after the urban planning project (Table 1). As observed in other studies, when an urban system grows, intelligibility tends to decrease as cities often get more deformed and irregular in the way the centre is connected to the whole system (Ugalde et al. 2009).

- An emerging trend of the *third phase* and modern urban expansion is that axial lines have higher *Integration* values. The average *Local Integration* is 1.269 with min = 0.667 and max = 2.191. New and straight streets that connect the Medina through the equipment centre with modern urban areas and novel residential peripheries are well-connected streets. Moreover, the area where the main urban equipment of the city is located (Figure 8) appears now as one of the most integrated areas. Streets with high *Choice* values mostly include long modern streets that pass through the Medina. In fact, and according to the land-use maps, while integrated streets are distributed between equipment and commercial spaces, streets with high *Choice* values mainly connect residential areas in the peripheries with the equipment and commercial cores (Figure 8).

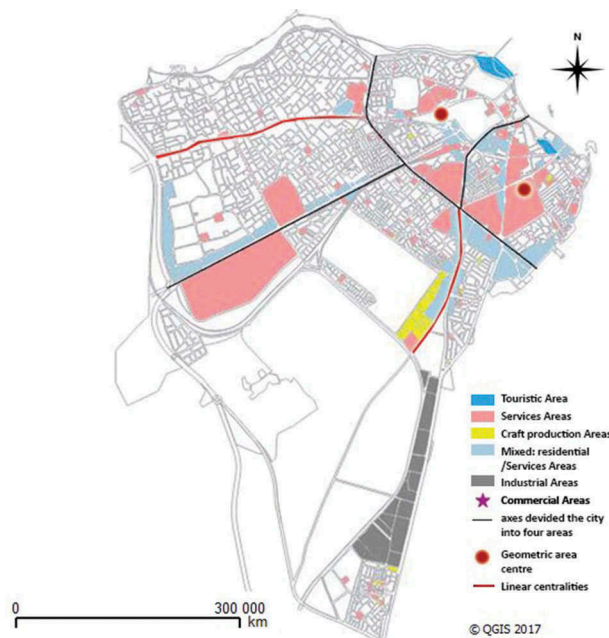


Figure 8. Localization of centres and emergence of linear centralities.

The rapid spatial expansion of the network in this phase, accompanied by the increasing number of axial lines, resulted in an important number of streets becoming more connected to each other and more connected to the longest line of the system (Figure 7).

Figure 7 also illustrates the effect of the network expansion of the city of Monastir and the transition from a centralized urban system to an interconnected urban system. The axial map that emerges in 2013 represents the 'decentralization' period. This axial map is made up of 1731 street segments with an average length of nearly 189.16 m. Until 1974, the city was perceived as a monocentric structure with 'satellites' that denoted residential sites. This therefore explains why this axial system has the longest average line length in the third phase as these satellites had to be connected with the main urban core, and this mainly

Table 1. Summary of measures in the city of Monastir through three periods of development (1956, 1974 and 2013).

Variable	1956			1974			2013		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
Degree	1	4.41	15	1	4.91	22	1	5.02	41
Global integration (R_n)	0.53	1.15	2.08	0.66	1.26	2.19	0.71	1.34	2.49
Local integration (R_3)	0.42	1.74	3.47	0.33	2.03	3.49	0.33	2.15	4.23
Synergy		0.77			0.67			0.59	
Intelligibility		57%			35%			32%	
Average length of street segments (m)		34.34			34.87			189.16	

with continuous long street segments. Connectivity and Integration values are the highest ones during that period, and both at the local and global scales. *Connectivity* has an average value of 5.02, *Local Integration* 2.15 while *Integration* scores an average of 1.34. However, *Intelligibility* and *Synergy* figures have dropped (i.e. *Intelligibility* average is 0.32 whereas *Synergy* average is 0.59). Even though both local and global integration values have increased, the synergy of the urban system still managed to decrease. This is due to the fact that the gap between local and global scales has increased. It is indeed non-straightforward to identify the reasons behind this trend, but one might guess that the different areas are more integrated in the local level. Moreover, as there was not really an urban strategy in the city against this spectacular urban sprawl, the urban system is not coherent and presents several discontinuities.

The longest street segment (Figure 7(a)) that represents the road which connects Monastir to Kairouan also divides the city and has the higher *Integration* ($Rn = 2.49$) and *Local Integration* ($R3 = 4.23$) values. It also appears that this avenue has the highest measure of *Choice* ($Rn7 = 61,101$). This avenue in fact denotes the most important connection between the old and consolidated urban fabric of the city. Hence, this road plays a major role in favouring people's movement traffic flows in the city. The continuity of this avenue shapes the distribution of the residential plots and commercial areas in a prominent linear centrality at the city scale. Furthermore, the measure of *Local Integration* reveals the different resorts that make up the city of Monastir (Figure 7) and the new 'linear centralities' that emerge in the city area (Figure 8). Unplanned urban expansion of this period causes the dependence to the original urban network. In fact, this linear growth seems to anticipate the formation of 'linear centralities'. On the other hand, high global to-movement values denoted by the measure of *Integration* coincides exemplarily with variety in land use and commerce areas located there, whereas high through-movement (*Choice*) tends to reinforce uses related to local centralities.

4. Comparative results and discussion

The evolution and cross-comparison of the local and global space syntax variables, as they appear on the different phases of the development of the city of Monastir, help us to analyse different structural patterns as well as the multiple forms of centrality that emerge (Table 1 for a summary). The measures of *Local Integration* and *Integration* mainly represent local and global displacement opportunities for a given street in

the network, respectively. The measure of *Choice* evaluates the potential for each street segment to be taken when applying a shortest path algorithm. *Integration* mainly evaluates the degree of convergence and dispersion of the axial lines in the whole urban system, while *Local Integration* is applied to understand the local street structure, while be indicative of potential 'new centres' at the local scale. The objective is to identify the dominant foreground network, marked by linear continuity and the background network with less linear continuity (Hillier 2009).

As reflected in Table 1, there is a decrease of both *Synergy* and *Intelligibility* values over time. This is one of the effects of zonal planning and transportation engineering and whose objectives are to separate the global route structure from the local neighbourhood. As illustrated by the scattergram, this denotes the fact that a small number of the most integrated spaces are also being poorly locally connected (Hillier, 2006).

Overall, it appears that the average values of *Integration* are relatively similar on the three phases of development of the city of Monastir, but maximum values increase for all space syntax measures to reflect the increase of the number of axial lines. It also appears in Figure 7 that the morphological development of the city emphasizes the role of the city centre and a hierarchical dependency towards the other peripheral centres.

The variable of *Integration* presents very close values on the three development phases. However, when comparing the successive axial maps (Figure 7) it is possible to conclude that (a) the most integrated areas are concentrated in the Medina, (b) the core in the historic centre spreads its accessibility towards three directions after the project of modern development and (c) finally the regional perspective emphasizes the axial lines that connect the new centre area to the surrounding settlements.

The values that appear for the measure of *Integration* reinforce the interconnected character identified of the urban area of Monastir. The axial map shows that the most integrated axial lines correspond to the new centre area (Figure 6). The *Synergy* is reduced from 77% (1956) to 59% (2013) which is an important of many urban and transportation planning studies that separate in modern cities, the global route structure from local neighbourhoods. The *Intelligibility* values decrease reaching only 32% (1956 average is 57%). The degree values are relatively high, but they progressively and slightly decreased over time. The findings seem to outline a decreasing ability to comprehend the entire city structure throughout the arrangements of the local parts.



Figure 9. Main planning features and historical morphological phases of Monastir.

The axial and segment line maps illustrated in Figure 9 also indicate that the streets with high *Integration* values also have high *Choice* values. The most integrated streets of the second temporal phase are located between the commercial cores of Medina and residential zones of modern extensions towards the South, while in the third temporal phase (Figure 7), they are located at the edges of organic urban entities and pass around large urban subdivisions of institutional, administrative and commercial activities in the south-west. Nevertheless, a decrease is also detected in the *Synergy* values of the whole urban network, suggesting a loss of synchronization between the local street structure and the wider urban street context.

5. Discussion

The first two phases of development of the city of Monastir represent the former development of the modern city of Monastir, the *Global Integration* shows that the historic centre appears as the active centre as denoted by the axial map illustrated in Figure 2. However, the third phase of development reveals a different reality as several roads from the centre appear and are connected to peripheral areas. In morphological terms, the impact of the central area is reduced as new surrounding areas develop their own connections. The new expansion zones surrounding the new centre have a considerable impact on the structural patterns by moving the original centralities to some roads that divided the original settlement and the outskirts of the city.

It appears that for a relative long period, the syntactic core of the city remains within the Medina, showing a strong correlation with its commercial core. This correlation is interrupted after 1974, when

due to modern management, the syntactic core of the city moves outside Medina. Consequently, a new core emerges along this new syntactic core in addition to the old historic core. The diachronic study of the city also reveals a strong correlation between the syntactic core defined by the urban streets with high *Integration* and that defined by the streets with high *Choice*.

The analysis of the urban sprawl of the city of Monastir shows that its original centre 'lost' its centrality to be benefit of the new one. The orthogonal grid of the new city centre establishes a main functional hierarchy of the urban system that caused this 'decrease of centrality'. On the other hand, the urban expansion of Monastir along the main roads relating the city to the ones of Mahdia, Kairouan and Sousse generates a novel form of continuity amongst the different resorts of the city, generating a sort of distributed urban system.

Accordingly, it has been possible to identify the emergence of several 'Axes of linear centralities' that connect the new resort networks with the city created in 1974. These results are supported by the fact, as outlined by Hillier, that the urban network is formed from the aggregation at the local scale, justifying the importance of space syntax multiscale analysis. The continuity of the linear circulation system along the south-western axis is also an intrinsic characteristic of Tunisian cities. This is related to the fact that there was a lack of long-term urban planning policy. Thus, this highlights the applicability and importance of the multiscale syntactic analysis in relation to the emergence of new centralities.

In examining the street network over this period, a configurational analysis revealed two fundamental properties of the urban structure: its ever-changing centrality and the differentiation of local parts in their global context.

Since mean global integration decreased over time, it was suggested that the street network became less centralized over time. On the other hand, the central core, of each period, comprises the main arteries, the principal place in the city where people are interacting with each other. The results also showed that the appearance of new structural elements such as 'linear centralities' are a consequence of urban planning decisions. These emerging centralities have an important impact on the overall layout of the city and its hierarchical structure, as well on the way social relations are likely to develop on the urban realm. This finding suggests that space syntax techniques are of value to urban researchers, not only as descriptive tools, but also as to model how the street grid influences human behaviours and displacements. For the last

period, we observe the emergence of a novel structural hierarchy in the city, being not only a consequence of the city growth but also of a redistribution of the notion of centrality in the city of Monastir.

6. Conclusion

The research developed in this paper applies space syntax principles to provide a modelling framework for a diachronic and synchronic study of a specific Sahelian urban landscape. Our study is applied to the city of Monastir, a typical example of a Sahelian city, in order to illustrate how space syntax can be used to derive a better knowledge of the relationships between the evolution of urban forms and land-use patterns at different scales and times. Our study shows that the main urban and structural forms of the city of Monastir, taken as a representative example of a Sahelian city, are the result of directed urban planning and construction interventions in the first phase of development, but rather of spontaneous and self-emerging development in the second period.

When applied to a series of urban maps, it appears from our study that space syntax provides an effective computational framework to analyse the main structural, dominant, hierarchical and centrality/periphery dualism patterns that evolve and appear over time. Such trends can be further compared to urban planning decisions in order to search for some possible correlations. Overall, the measures and analysis provided by space syntax approaches should be considered as providing some preliminary insights on the structural representation of an urban network, additional metrics and semantics being additional variables that can complete the structural analysis, according to the range of phenomena studied (e.g. traffic patterns). For instance, the analysis made does not consider a finer level of granularity in the structural analysis (e.g. difference made between sidewalks and car lines). However, making a difference between for instance sidewalks and car lines is an interesting direction to explore. The analysis is also mostly topological and based on the application of a series of graph measures as the initial objective of space syntax, as introduced by Hillier, was to study 'the influence of spatial configuration on social life'. Additional metrics, inspired for example from network analysis, can provide some valuable directions still to consider (e.g. derivation of traffic patterns and allocation measures). Those are directions for further work we plan to explore. We also plan to apply the whole approach to additional Sahelian cities, as well as to other regional contexts. Not only our framework should be further experimented but also closely related to previous literature on urban development in the

considered cities, as well as it might provide some insights on further urban planning actions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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